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# PRODUCTIVITY AND PROFITABILITY OF GRAPPLE YARDING B.C. COASTAL SECOND GROWTH TIMBER 1/

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## ABSTRACT

A Madill 122 yarding crane was monitored over a two-month period in 1987 in a coastal B.C. second-growth stand. Productivity, costs, and profitability were determined. Although productivity and costs averaged 34.7 $m^3$ per productive machine hour and \$5.68/$m^3$ respectively, marginal economics analysis showed 24-46% of J-grade logs, 77-85% of X-grade logs, and 100% of Y-grade logs were yarded at a loss. The main factor influencing yarding profit was turn volume with yarding distance having a lesser effect.

## SUMMARY

The Canadian Forestry Service, under the Forest Resource Development Agreement (FRDA), contracted FERIC to examine the profitability of grapple yarding second-growth timber. The study block was located approximately 15 km northwest of Sooke, B.C., and the stand composition was mainly second-growth Douglas-fir. A Madill 122 yarding crane was monitored on a shift-level basis over a two-month period, and at a detailed-timing level for three weeks. During the detailed-timing period, individual logs were scaled and graded, and their yarding time recorded. The yarding costs and profits of these logs were calculated using marginal economics analysis techniques.

The yarding crane averaged 232 $m^3$ per 8-hour shift and 34.7 $m^3$ per productive machine hour. The average cost per cubic metre was $5.68.

Depending on species, between 24 and 46% of J-grade logs did not produce enough revenue to pay for their yarding costs when yarded individually. Between 77 and 85% of X-grade logs were unprofitable. All of the Y-grade logs were unprofitable regardless of species. Marginal log sizes for each species, by log grade, were determined. The major factor influencing the profitability of a log was turn size with yarding distance having a lesser influence.

Grapple size and design influenced yarder productivity. A large grapple with more teeth was able to grip small logs better than a small grapple and thus productivity was improved.

## INTRODUCTION

As high-quality, old-growth timber becomes more scarce, logging operators are looking at second-growth stands for part of their timber supply. The main objectives of this study were to examine the profitability of grapple yarding in second-growth timber, and to examine the factors which determine the marginal log. The marginal log is the one for which its variable yarding cost is equal to its value at roadside. Harvesting a log of greater cost, or lesser value, than the marginal log will reduce the net income earned on the setting. Logs above the margin fully offset their variable logging cost and contribute towards paying off fixed costs. FERIC was contracted by the Canadian Forestry Service under the Forest Resource Development Agreement (FRDA) to carry out the study.

A secondary objective of the study was to evaluate the Madill 122 yarding crane, and to report on its costs and productivities. The Madill 122 is a new generation yarding crane manufactured by S. Madill Limited in Nanaimo, B.C. It is designed to be more effective in yarding smaller timber than the larger yarding cranes more common on the coast of B.C.

The study area was logged under contract for British Columbia Forest Products Limited, Renfrew Logging Division. The area was located near Scoke, B.C. and had been previously logged in the 1890s. Data in this report have been obtained through detailed on-site measurements of yarding operations.

## STUDY APPROACH AND PROCEDURES

Two study methods were used: shift-level and detailed timing. A Model DSR Servis Recorder was mounted on the yarding crane, and a chart was produced for each shift worked. The operators identified each delay over 10-min duration on the chart and provided an explanation of its cause. Log volumes were derived from the operator's daily piece counts and the piece average obtained from the company's production records.

Detailed-timing data were collected using timing boards and stop watches. In Week 1, sample logs were marked, scaled, and graded prior to yarding, and in Weeks 2 and 3, sample logs were scaled and graded after yarding. This change was made because the former scaling method was expensive and many of the scaled logs were yarded on shifts when there was no detailed timing. A portion of the identification marks were obliterated during yarding, loading, and hauling in Weeks 2 and 3, but we were still able to identify individual logs in approximately 10% of the turns. All scaling and grading was done to B.C. Ministry of Forests and Lands standards by licenced scalers.

Delay times were divided into two classes--over and under 10-min duration. Delays under 10 min were considered productive time, while delays over 10 min were classified as non-productive time. Non-productive time was further divided into mechanical and non-mechanical delays.

The study was carried out over a period of two months. Shift-level data were gathered on 79 production shifts, and during three weeks of this period, more detailed information was collected on 2730 yarding cycles ("turns"). A total of 281 of these turns contained marked pieces for which species, grade, and volume information was recorded.

The labour rates used in the cost analysis are current IWA rates plus 35% burden. Machinery costs are FERIC estimates based on information from equipment and supplies distributors and are not actual costs incurred by the company or contractor. Costs such as supervision, overhead, and crew and machinery transportation are not included. Interest costs are shown in Appendix I but are excluded from the calculated yarding costs.

## SITE AND SYSTEM DESCRIPTION

The study site was situated on the west coast of Vancouver Island, 15 km northwest of Sooke, B.C. The stand was established in approximately 1900 after the original stand had been logged. Old-growth stumps left after the initial logging were scattered throughout the area. Species composition was 66% Douglas-fir, 10% western red cedar, 15% western hemlock, 4% Sitka spruce, 1% lodgepole or western white pine, and 4% alder. Table 1 shows a description of the site and Table 2 shows the species and grade distribution. The range in piece size is only for those pieces marked and scaled for FERIC. Piece average, volume per hectare, and species and grade distribution are derived from the company's production records during the study. The log grades shown are B.C. Ministry of Forests and Lands statutory grades. Common usage log-grade definitions are also included in Table 2.

TABLE 1. Site Description.

| | |
|---|---|
| Cutting Area - Study area | 50.5 ha |
| - Total setting | 91.7 ha |
| Slope - Range | 0-50% |
| - Average | 5% |
| Terrain | Flat |
| Exposed Rock | None |
| Underbrush | Moderate to Heavy |
| Obstacles | - Some Windfalls<br>- Old-Growth Stumps |
| Volume/ha - Net, as produced | 343 $m^3$/ha |
| Piece Size | |
| - Range | 0.12-8.17 $m^3$ |
| - Average | 0.75 $m^3$ |

TABLE 2. Species and Grade Distribution.

| Species | Species (%) | Grade (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C | H | I | J | K-M | X | Y | - | Total |
| Fir | 66 | 11 | 33 | 4 | 46 | | 6 | | | 100 |
| Cedar | 10 | | 12 | 18 | 50 | 6 | 13 | 1 | | 100 |
| Hemlock | 15 | | 2 | 15 | 71 | | 12 | | | 100 |
| Balsam | <1 | | | 25 | 55 | | 20 | | | 100 |
| Spruce | 4 | 4 | 16 | 9 | 53 | | 14 | 4 | | 100 |
| Pine | 1 | | 30 | 3 | 47 | | 18 | 2 | | 100 |
| Alder | 4 | | | | | | 3 | | 97 | 100 |
| Total | 100 | 7 | 24 | 7 | 48 | 1 | 8 | 1 | 4 | 100 |

Grade Definitions:

C - Peeler
H - Sawlog
I - Sawlog
J - Small Sawlog
K-M - Shingle
X - Low-Grade Sawlog
Y - Pulp

The logging area was flat so the setting boundaries were determined by limits such as the property line, Highway 14 right-of-way, and scrub timber rather than terrain features. The backspar had easy access to most parts of the setting, except where surface water collected and the ground would not support its weight. There were several gravel ridges (4- to 8-m high and 7- to 10-m wide on the top) bisecting the area. These ridges were used for haul road locations to improve deflection for the yarding crane. They also provided excellent material for road construction.

The area was handfelled and the trees bucked to specified log lengths. Most tops and limbs were removed at the felling site. Trees were felled parallel to the truck roads to improve yarding efficiency.

Yarding was done with a 1985 Madill 122 yarding crane with a Hitachi UH14 mobile backspar. Logs were yarded to the roadside and decked in windrows. The Madill 122 is shown in Figure A. Table 3 shows a summary of the yarder specifications and a more complete list is shown in Appendix II.

Each yarding crew consisted of a machine operator and a hooktender. The hooktender aided with guyline moves as well as spotting logs and moving the backspar. The yarding crane was normally operated for two shifts per day, but a third shift was added for a portion of the study period. FERIC considers the two regular operators to be average in skill and efficiency, but the third operator was unfamiliar with the Madill 122 and was considered to be a trainee operator. His times have been included in the shift-level study, but excluded from the detailed-timing study.

FIGURE A. Madill 122 Yarding Crane.

TABLE 3. 1985 Madill 122 Yarding-Crane Specifications.

| | | |
|---|---|---|
| Engine: | GM 8V92TA 315 kW (425 HP) | |
| Undercarriage: | B7H Hydrostatic Drive | |
| Tower Height: | 16.5 m | |
| Guylines: | 2--walking type | |
| Standard Weight: | 50 800 kg | |
| Interlock: | Slip clutch | |
| Swing: | Hydraulic | |
| Winch Specifications @ Mid Drum: | Main | Haulback |
| Pull | 234 kN (52 600 lb) | 109 kN (24 600 lb) |
| Speed | 673 m/min | 819 m/min |
| Capacity | 427 m of 22-mm line | 1550 m of 19-mm line |

A Washington TL-6 Trakloader and Prentice 810B hydraulic loader were used for loading. In addition, a Timberjack cable skidder and Caterpillar 966 wheeled loader worked together to log any isolated patches which were inaccessible to the yarding crane. Logs were hauled on highway trucks to B.C. Forest Product's Shoal Island log sort. Loading and hauling operated on day-shift only.

## RESULTS AND DISCUSSION

The first sections deal with the setting characteristics and the shift-level study. Then the detailed-timing data are analyzed, a model is developed for the total turn time, and the model is used to predict yarding costs by distance and turn volume. Yarding costs of the marked logs are examined in the next section, and this information is used to predict the marginal log. Finally, some mechanical aspects of the yarding crane are discussed.

### 1. Setting Layout

Slope on the setting ranged from 0-10%, except along the gravel ridges where it reached 50%. The maximum yarding distance observed in the detailed-timing period was 220 m, but a 280-m-long corner was noted during the shift-level monitoring period. Yarding deflection was good during the detailed-timing period, especially because of the additional height provided by the road location. The logging "chance" on the setting was very good overall, with only isolated areas of difficult yarding. The difficult areas were generally where the road was not on a ridge and yarding deflection was reduced. Figure B shows the general setting layout and the study area locations.

### 2. Shift-Level Analysis

The Servis recorder was mounted on the yarding crane for 79 production shifts. The first five days of the study were day-shift only. There were three shifts per day for 14 days (42 shifts), and the normal two shifts per day operated for 16 days (32 shifts). The third shift was temporary, while the trainee operator's regular yarding crane was undergoing major repairs.

During the 79 shifts, 23 014 pieces were yarded and the piece average was 0.75 $m^3$/piece. Production averaged 291 pieces per shift. Total volume yarded was 17 343 $m^3$ for an average of 232 $m^3$ per 8-hour shift. Table 4 gives a summary of the time distribution during production shifts. (Further detail can be found in Appendix III.) The Madill 122 averaged 34.7 $m^3$/PMH, and 6.3 PMH/shift over the study period. The third shift was scheduled for 6.5 hours per shift, accounting for the short average shift length.

The productive yarding time shown in Table 4 includes delays under 10 min in duration. The total machine time was about 600 hours. At an estimated cost of $164.36 per hour for yarder, backspar, and crew, average yarding cost becomes $5.68/$m^3$.

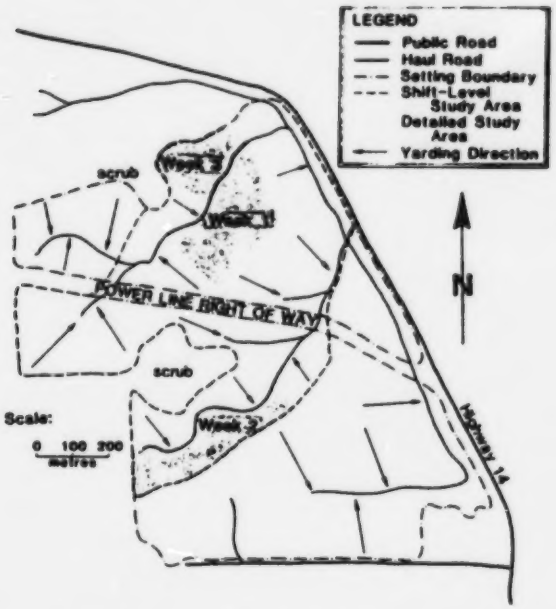



FIGURE B. Setting Layout.

TABLE 4. Shift Level Time Distribution--Shifts with Production.

| Phase | Hours | Hours/Shift |
|---|---|---|
| Productive Machine Hours (PMH) | | |
| Yarding Time | 479.9 | |
| Move/Rig | 18.7 | |
| Change Grapple | 1.7 | |
| Subtotal | 500.3 | 6.3 |
| Non-Mechanical Delay Time | | |
| Operational | 21.5 | |
| Organizational | 9.1 | |
| Subtotal | 30.6 | 0.4 |
| Mechanically Ready Hours (MRH) | 530.9 | 6.7 |
| Mechanical Delay Time | | |
| Mechanical Wait | 9.9 | |
| Repair | 46.3 | |
| Service | 12.8 | |
| Subtotal | 69.0 | 0.9 |
| Total Machine Hours (TMH) | 599.9 | 7.6 |
| Productive Time Ratio (PTR = PMH/TMH) | 83.4% | |
| Availability (A = MRH/TMH) | 88.5% | |
| Productive Shifts | 79 | |
| Pieces Yarded | 23 014 | |
| Volume Yarded | 17 343 $m^3$ | |
| Production/PMH | 34.7 $m^3$/PMH | |
| Pieces/PMH | 46.0 pieces/PMH | |

Non-mechanical delay time occurs when the yarding crane is mechanically ready for work but is unable to work due to organizational or operational delays. Organizational delays are generally controllable by company policy (e.g., safety meeting during work hours), while operational delays are not (e.g. backspar is stuck). The majority of the operational delay time (13.8 hours) was due to repairs on the backspar. Shift changes accounted for 6.2 hours of the organizational delay time.

Mechanical delay time occurs when the yarding crane is not mechanically ready for work. Most of the mechanical wait time (7.5 hours) occurred on January 2, 1987 when many businesses were closed, and repair parts were unavailable. Table 5 shows further details on repair and service, both in-shift and out-of-shift (weekends).

TABLE 5. Summary of Maintenance.

| | In-Shift | Out-of-Shift | Total |
|---|---|---|---|
| Repairs | | | |
| Carrier | 5.5 | 16.0 | 21.5 |
| Power System | 4.7 | 4.0 | 8.7 |
| Winch/Lines/Grapple | 35.9 | 0.0 | 35.9 |
| Unspecified Repairs | 0.2 | 0.0 | 0.2 |
| Repair Total | 46.3 | 20.0 | 66.3 |
| Service | | | |
| Carrier | 1.6 | 0.0 | 1.6 |
| Winch/Lines/Grapple | 1.9 | 0.0 | 1.9 |
| General | 9.3 | 0.0 | 9.3 |
| Service Total | 12.8 | 0.0 | 12.8 |
| Total | 59.1 | 20.0 | 79.1 |
| Mechanical Downtime Ratio | | | 15.8 |

The mechanical downtime ratio (MDR) is the number of repair or service hours needed to achieve 100 productive machine hours. The MDR was 15.8 during this study. Although the yarding crane required 79.1 hours of repairs and service to achieve 500.3 productive machine hours, some of these repairs do not reflect accurately its expected long-term performance. For example, the original two air compressors on the yarder were unable to meet the compressed air demand during short-distance yarding. S. Madill Limited supplied and installed an additional air compressor, then one of its hydraulic supply lines burst shortly after installation. Total installation and repair time was 19.2 hours. If the installation and repair of the additional air compressor had not occurred, the MDR would have been 12.0 and the availability would have been 89.0%. Also, 30 hours were spent repairing the log grapple, the main, slackpulling, and haulback lines, and the grapple opening and

closing lines. These repairs are attributed more to accessory equipment than to the yarder itself.

However, there were some recurring problems on the yarder, especially in the winch interlock, that will affect long-term performance. The slip clutch in the interlock malfunctioned several times causing the grapple to open and drop logs during inhaul. Eight repairs totalling 9.9 hours were required. Also, the mainline brake stuck in the "on" position. Repairs took 3 hours.

### 3. Detailed-Timing Results

The detailed timing covered three different operating conditions. Week 1 required the use of guylines, Weeks 2 and 3 did not. Week 1 had long-distance yarding, Week 2 had short-distance yarding, and Week 3 had moderate-distance yarding. Table 6 shows the production summary for the detailed-timing periods. Average time per turn shown includes all yarding and moving time, and delay time up to 10 min. Week 3 not only had 3% more turns per PMH, but also 11% more pieces per PMH than Week 2 because of more logs per turn. This shows the importance of maximizing the number of logs per turn. The shift-level piece average (0.75 $m^3$) was used to calculate volumes, and the Madill 122 averaged 43.0 $m^3$/PMH during the detailed-timing period.

TABLE 6. Production Summary--Detailed Timing.

| | Week 1 | Week 2 | Week 3 | All |
|---|---|---|---|---|
| Avg Yarding Distance (m) | 92 | 46 | 72 | 77 |
| Max. Yarding Distance (m) | 220 | 135 | 160 | 220 |
| No. of Turns | 1478 | 647 | 605 | 2730 |
| Pieces Yarded | 1715 | 772 | 780 | 3267 |
| Productive Time (h) | 34.4 | 11.9 | 10.8 | 57.1 |
| No. Logs/Turn | 1.16 | 1.19 | 1.29 | 1.20 |
| Volume Yarded ($m^3$) | 1292 | 581 | 587 | 2460 |
| Avg Time per Turn (min) | 1.39 | 1.10 | 1.07 | 1.25 |
| Turns per PMH | 43.0 | 54.4 | 56.0 | 47.8 |
| Pieces per PMH | 49.9 | 64.9 | 72.1 | 57.2 |
| Volume per PMH ($m^3$) | 37.6 | 48.8 | 54.3 | 43.0 |

Table 7 shows a summary of productive time. The times are calculated from all observations regardless of whether or not the log had been scaled. Machine active time accounted for 88% of productive time. The remaining 12% of productive time was comprised of delays such as check yarding road, short duration mechanical delays, FERIC delays, untangle lines, move vehicles, clear landing debris, and operator training.

TABLE 7. Summary of Productive Time--Detailed Timing.

| Phase | Week 1 | | Week 2 | | Week 3 | | All | |
|---|---|---|---|---|---|---|---|---|
| | Hours | % | Hours | % | Hours | % | Hours | % |
| Machine Active | | | | | | | | |
| Move Yarder | 1.9 | 6 | 1.8 | 15 | 0.5 | 5 | 4.2 | 7 |
| Move Backspar | 1.3 | 4 | 1.4 | 12 | 0.8 | 7 | 3.5 | 6 |
| Net Yarding Time | 27.7 | 80 | 7.1 | 60 | 8.2 | 76 | 43.0 | 75 |
| Subtotal | 30.9 | 90 | 10.3 | 87 | 9.5 | 88 | 50.7 | 88 |
| Short Delay (<10 min) | | | | | | | | |
| Check Yarding Road | 0.5 | 2 | 0.7 | 6 | 0.4 | 4 | 1.6 | 3 |
| Yarder--Mech. Delay | 1.0 | 3 | 0.3 | 3 | 0.3 | 3 | 1.6 | 3 |
| Backspar--Mech. Delay | 0.8 | 2 | 0.2 | 1 | 0.0 | - | 1.0 | 2 |
| Miscellaneous | 1.2 | 3 | 0.4 | 3 | 0.6 | 4 | 2.2 | 4 |
| Subtotal | 3.5 | 10 | 1.6 | 13 | 1.3 | 12 | 6.4 | 12 |
| Productive Time | 34.4 | 100 | 11.9 | 100 | 10.8 | 100 | 57.1 | 100 |

Note from Table 6 that the shortest yarding distance was recorded in Week 2, but that Week 3 had the lowest average turn time. Table 7 shows that the net yarding time in Week 2 dropped to 60% of productive time, and that move times rose to 27% of productive time. This indicates that move times on short yarding roads can increase to such a point that productivity is decreased. Total turn time appears to be minimized when maximum yarding distance is between 140 and 160 m.

Table 8 shows the distribution of short-duration mechanical delays. The winch repair was adjustment of the mainline brake band. The backspar bucket-tilt hydraulic lines were poorly protected and subject to mechanical damage from the grapple. Much of the move backspar time from Table 7 was spent in pushing logs in the clear in an effort to avoid such damage.

TABLE 8. Summary of Mechanical Delays Under 10 Minutes Duration--All Weeks Combined.

| Mechanical Delays | Hours |
|---|---|
| Yarder | |
| Grapple - Lines | 0.2 |
| - Service | 0.2 |
| Haulback Rider Block | 0.1 |
| Winch | 0.3 |
| Fuelling | 0.3 |
| Warm-Up | 0.3 |
| General Service | 0.2 |
| | 1.6 |
| Backspar | |
| Hydraulic Lines | 0.8 |
| Broken Petcock | 0.2 |
| | 1.0 |

4. Cycle Elements

Table 9 shows the average time per turn for each of the cycle elements (trainee operator time is excluded). Cycle elements are defined in Appendix IV. The net yarding time for Week 2 was 0.29 min less than the average. The short yarding distance meant shorter outhaul and inhaul times, accounting for 0.19 min of the difference. The remaining 0.10 min comes mainly from hookup time. The low hookup time is a reflection of better operator visibility, and of improved deflection nearer the roadside. "Spotting" occurs when visibility is limited and the hooktender guides the yarder operator to the log via radio communication. FERIC observed that spotted turns generally had longer hookup times. During Week 1, FERIC noticed the yarder operator had difficulty in raising the grapple clear of the ground at distances over 180 m and this resulted in longer hookup times.

Rehook is the time required to rehook the log after it has slipped from the grapple. It does not include those times when the operator deliberately released the log to rehook it in a better position. The rehook time for Week 2 was the lowest overall which is an indication of better visibility and better deflection.

"Cherry-pick" is a term normally associated with log loaders and refers to gathering and loading the roadside right-of-way logs prior to yarding. It is not normally a function of the yarding crane. However, scheduling problems prevented the contractor from cherry-picking before yarding, and the yarding crane had to move and align the right-of-way logs before building the log deck. Those logs which FERIC estimated would have normally been cherry-picked have been so classified. By Week 3, the loaders cherry-picked some right-of-way logs, and this was reflected in the drop in the cherry-pick time for the yarder. The average for Weeks 1 and 2 was 0.09 min per turn, while the average for Week 3 was 0.04 min per turn.

TABLE 9. Summary of Yarding Cycle Element Times.

| Cycle Element | Minutes per Turn | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | All |
| Outhaul | 0.23 | 0.10 | 0.17 | 0.19 |
| Hookup | 0.35 | 0.22 | 0.27 | 0.31 |
| Rehook | 0.04 | 0.02 | 0.05 | 0.04 |
| Inhaul | 0.26 | 0.10 | 0.17 | 0.20 |
| Unhook | 0.13 | 0.09 | 0.09 | 0.11 |
| Deck | 0.03 | 0.03 | 0.03 | 0.03 |
| Cherry-Pick | 0.08 | 0.10 | 0.04 | 0.07 |
| Net Yarding Time | 1.12 | 0.66 | 0.82 | 0.95 |
| Move Yarder | 0.08 | 0.17 | 0.04 | 0.09 |
| Move Backspar | 0.05 | 0.12 | 0.08 | 0.07 |
| Machine Active Time | 1.25 | 0.95 | 0.94 | 1.11 |
| Delay < 10 min | 0.14 | 0.15 | 0.13 | 0.14 |
| Turn Time | 1.39 | 1.10 | 1.07 | 1.25 |
| Percent of Turns "Spotted" by Hooktender | 49 | 16 | 48 | 40 |

The guylines were used on the yarding crane at all times during Week 1, and seldom during Weeks 2 and 3. The yarder was able to work effectively at yarding distances up to 150-160 m without the guylines. At longer distances, or with large turns (over 3 $m^3$), the yarder showed some instability. Week 3 had the lowest move yarder time since the yarder was able to work without the guylines. Week 2 had the highest move yarder time because of the short yarding distance which caused frequent moves.

## 5. Regression Analysis

Regression analysis was carried out to estimate how inhaul times varied with turn volume and yarding distance. Linear relationships were tested using the least-squares method. As mentioned earlier, a sample of logs had been marked so that they could be individually identified as they were yarded. They were scaled and graded so their merchantable volumes and sales value could be determined. In addition, field tables were constructed showing piece volume by length, and by butt and top diameter classes. These tables (Appendix V) were used to estimate the volume class ($\pm$ 0.5 $m^3$) of some

unmarked logs. This method is not as precise as scaling, but does give an indication of the actual log size. Logs up to class 22 (estimated volume 11 $m^3$) were observed.

Initial analysis showed approximately the same inhaul time regression line for the first five estimated volume classes (up to 2.0 $m^3$). The low number of large-volume turns made 0.5 $m^3$ classes impractical. Therefore, the number of volume classes was reduced from 22 to 3: 2 $m^3$ and less, 2 to 3 $m^3$, and over 3 $m^3$. Regression equations were produced for each of these classes. The regression coefficients are shown in Table 10. These coefficients can be used to predict inhaul time as a function of yarding distance and turn volume. The equations have been forced through zero to eliminate negative inhaul times.

The average inhaul speed shown in Table 10 is the reciprocal of the regression coefficient. There appears to be a trend relating inhaul speed to turn volume. Larger turns have slower inhaul speeds. However, the model for yarding times and costs will be based solely on yarding distance because the lack of observations with turn sizes over 2 $m^3$ would result in questionable accuracy for a model that included turn size. Also, addition of turn size to the model would make it more complex to use.

TABLE 10. Correlation Between Inhaul Time in Minutes and Yarding Distance for Selected Turn Volumes.

| | $r^2$ | Regression Coefficient | No. of Observations | Average Speed (m/min) |
|---|---|---|---|---|
| Turn Volume <=2 $m^3$ | 0.69 | 0.00283 | 1130 | 353 |
| 2-3 $m^3$ | 0.73 | 0.00320 | 24 | 319 |
| > 3 $m^3$ | 0.82 | 0.00352 | 18 | 284 |
| All | 0.69 | 0.00284 | 1172 | 352 |

Example: Yarding Distance = 140 m

| | Turn Volume = 1.0 $m^3$ | Turn Volume = 4.0 $m^3$ |
|---|---|---|
| By "Class" Equation | Inhaul = 0.00283 x 140 = 0.40 min | Inhaul = 0.00352 x 140 = 0.49 min |
| By "All" Equation | Inhaul = 0.00298 x 140 = 0.42 min | Inhaul = 0.00298 x 140 = 0.42 min |

In developing the model for yarding times and costs, regression analysis was carried out to estimate linear relationships between outhaul, hookup, inhaul, unhook, and net yarding times and yarding distance. Table 11 shows the correlation between these element times and yarding distance.

TABLE 11. Correlation Between Element Time and Yarding Distance ($r^2$).

| Element | Week 1 | Week 2 | Week 3 | All |
|---|---|---|---|---|
| Outhaul | 0.77 | 0.45 | 0.72 | 0.71 |
| Hookup | 0.07 | 0.04 | 0.05 | - |
| Inhaul | 0.66 | 0.51 | 0.63 | 0.65 |
| Unhook | 0.01 | 0.00 | 0.07 | - |
| Net Yarding | 0.48 | 0.17 | 0.41 | - |

It appears there is a strong correlation between outhaul and inhaul times and yarding distance. There is little or no correlation between hookup or unhook times and yarding distance. There is a correlation between net yarding time (sum of all yarding elements) and yarding distance, but it is not as strong as the individual correlations for outhaul and inhaul because of variability in the hookup, unhook, deck, and cherry-pick times.

The correlations for all elements and net yarding time for Week 2 are not as strong as those for Weeks 1 and 3. Week 2 had a relatively short yarding distance and the grapple spent less time on each outhaul or inhaul cycle travelling at the maximum winch speed. Therefore, the inhaul and outhaul times were influenced more by unmeasured variables such as rate of acceleration, hang-ups, stop-and-start, and log alignment than would be on longer yarding distances.

The regression coefficients developed above were used to predict outhaul and inhaul times and are shown in Table 12. The regression lines were not forced through zero because a fixed yarding time was added. Times for elements such as hookup, unhook, and short delays have been taken from Table 9 and added to the regression equations to produce a model for total turn time. The total turn time must be adjusted by the productive time ratio to account for long delays.

Using the regression equations shown in Table 12 and the machine costs from Appendix I, it is possible to estimate the cost of each turn. The machine cost is $164.36 per hour, including the crew, yarding crane, and backspar, but excluding supervision, overhead, transportation, and interest. Table 12 shows the predicted times and costs per turn by yarding distance. Figure C shows the predicted turn times.

The costs per turn can be combined with turn volumes to estimate yarding costs per cubic metre by yarding distance or by turn volume. This is shown graphically in Figures D and E, and numerically in Appendix VI.

TABLE 12. Estimated Yarding Cycle Times and Costs--
All Weeks Combined.

| | | | |
|---|---|---|---|
| Outhaul | 0.02 | + | 0.00249 d |
| Inhaul | -0.06 | + | 0.00332 d |
| Fixed Yarding Time | 0.56 | | |
| Yarding Time | 0.52 | + | 0.00581 d |
| Moves, Delays | 0.30 | | |
| Total Turn Time | 0.82 | + | 0.00581 d |

Where: d is yarding distance in metres
time is predicted in minutes

productive time ratio = 83.4%

yarder and backspar cost = $164.36/h

| Yarding Distance (m) | Turn Time (min) | Turn Cost ($) |
|---|---|---|
| 20 | 1.12 | 3.08 |
| 40 | 1.26 | 3.46 |
| 60 | 1.40 | 3.84 |
| 80 | 1.54 | 4.22 |
| 100 | 1.68 | 4.60 |
| 120 | 1.82 | 4.98 |
| 140 | 1.96 | 5.37 |
| 160 | 2.10 | 5.75 |
| 180 | 2.24 | 6.13 |
| 200 | 2.38 | 6.51 |
| 220 | 2.52 | 6.89 |

The yarding costs increase linearly with yarding distance since the yarding time model is based on a linear function. However, the increase in yarding cost per cubic metre with increased yarding distance is greater with smaller turn sizes (Figure D). For example, the cost for a 0.25 $m^3$ turn increases by $12.21/$m^3$ when yarding distance increases from 20 m to 180 m, whereas it only increases by $0.76/$m^3$ for a 4 $m^3$ turn. The yarding cost per cubic metre decreases exponentially as turn size increases (Figure E). A small increase in turn size, from 0.25 $m^3$ to 0.50 $m^3$, decreases yarding cost at 100 m from $18.41/$m^3$ to $9.20/$m^3$. The importance of maximizing turn volume can be seen.

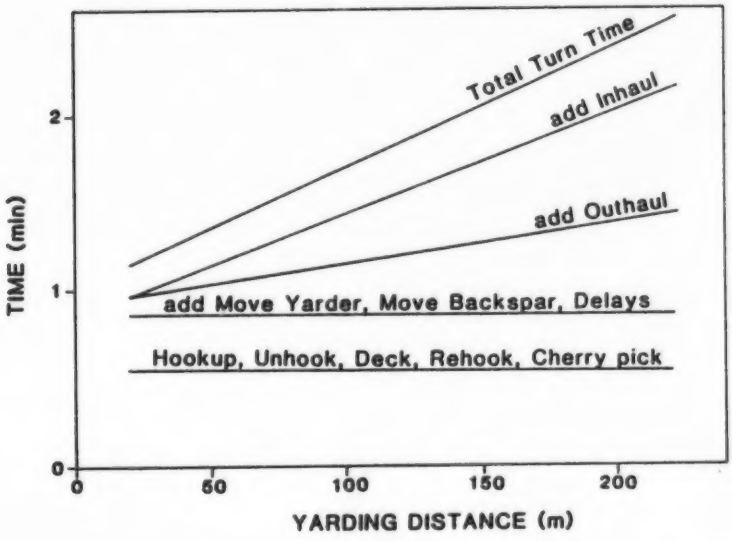



FIGURE C. Estimated Turn Time.

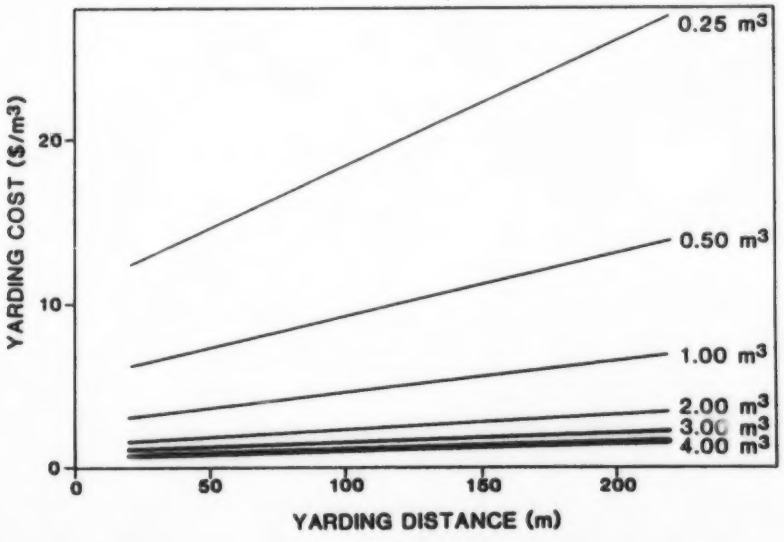



FIGURE D. Predicted Yarding Cost vs Yarding Distance for Selected Turn Volumes.

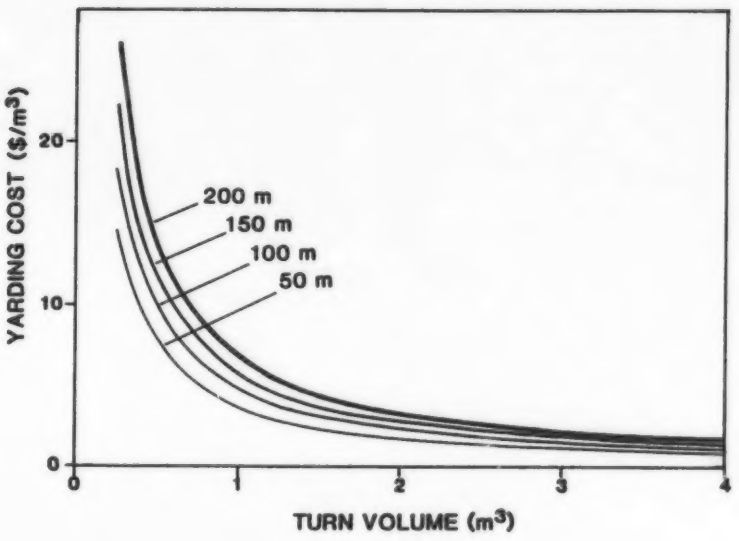



FIGURE E. Predicted Yarding Cost vs Turn Volume for Selected Yarding Distances.

## 6. Marginal Log Analysis

The marginal log is the one on which its variable yarding cost is equal to its net value at roadside. If yarding standards are determined according to marginal log analysis, net income will be maximized, regardless of the volume extracted from the setting. Fixed costs such as road development, falling, and yarder ownership do not enter into the marginal log analysis. Logs above the margin have value in excess of their yarding cost which help to recover fixed costs and eventually contribute to profit, while logs below the margin do not. Every submarginal log which is yarded decreases total profit.

The net log values and yarding costs for the 281 marked pieces were calculated. Vancouver Log Market prices as of February 1987 were used for market value. Costs for loading, hauling, sorting, booming and towing, sales expense, and stumpage were subtracted from the market value to calculate net value at roadside. All timber on the setting was assumed to be stumpage-bearing, although a portion was privately owned, and for ease of calculation was set at 8% of market value. Other costs have been estimated by FERIC. Loading and sorting are calculated on a per-piece basis, while hauling and towing are calculated on a per-cubic-metre basis. Sales expense has been set at 2.5% of market value. Appendix VII shows the market price used as well as the deductions.

The variable cost per hour for the yarding crane and backspar is $126.41 (Appendix I). An average short delay and move time was added to the observed yarding time for each of the 281 turns. This sum was divided by the productive time ratio from the shift-level study to calculate the turn time. This turn time was used to calculate the yarding cost for the profit analysis. Appendix VIII shows typical calculations for the Douglas-fir J-grade logs.

Figure F shows the yarding profit for the marked logs. All B-, C-, H-, I-, and M-grade logs had positive yarding profits. All Y-grade logs resulted in yarding losses. J- and X-grade logs in all species were near the profit margin.

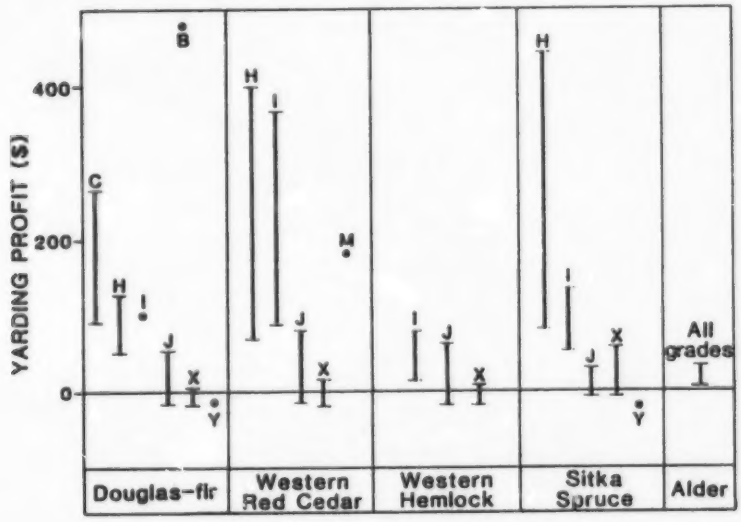



FIGURE F. Yarding Profit by Species and Grade.

Figure G shows the turn time versus yarding distance for Douglas-fir J-grade logs. There is a trend of increased turn time with increased yarding distance, although three logs have abnormally long turn times. These logs experienced "hang-ups" during inhaul, or excessive hookup times and longer turn times resulted. The yarding profit for Douglas-fir J-grade logs was plotted against turn time in Figure H. As expected, it shows the three logs with long turn times have low profits, but for turn times under 2 min, there does not appear to be a relationship between turn time and yarding profit.

Figures I and J show the yarding profit versus yarding distance and turn volume for Douglas-fir J-grade logs. It is clear that yarding profit is dependent on turn volume but the relationship between yarding profit and yarding distance is less clear. The three logs with long turn times are shown furthest from the regression line in Figure J. Figures G to J are typical for all species of J- and X-grade logs.

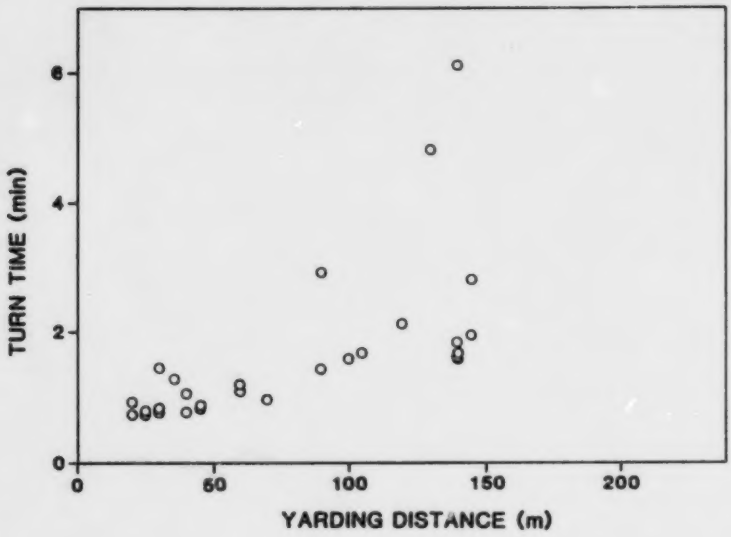



FIGURE G. Turn Time vs Yarding Distance--
Douglas-Fir J-Grade Logs.

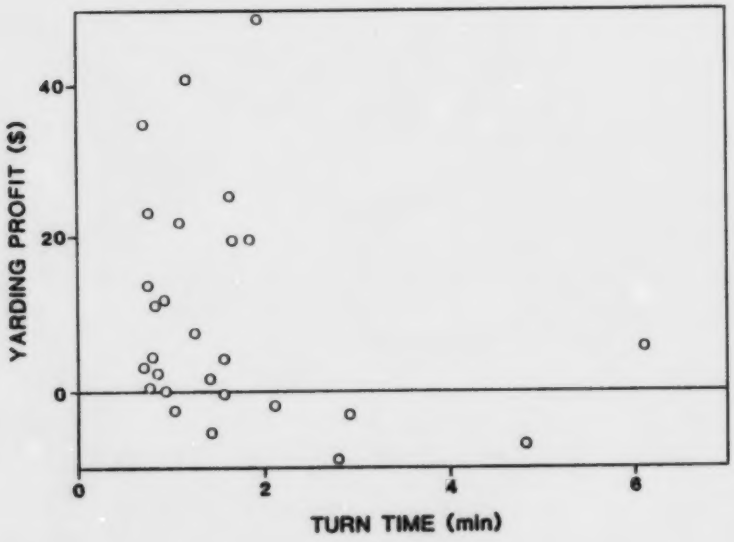



FIGURE H. Yarding Profit vs Turn Time--
Douglas-Fir J-Grade Logs.

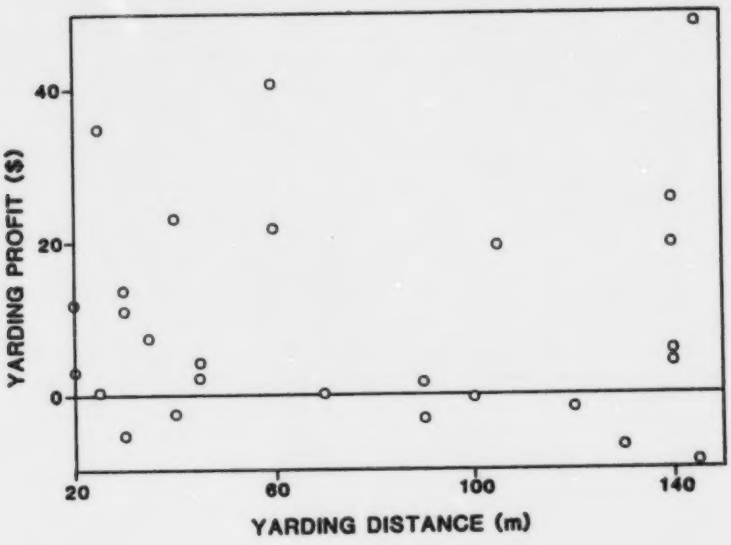



FIGURE I. Yarding Profit vs Yarding Distance--
Douglas-Fir J-Grade Logs.

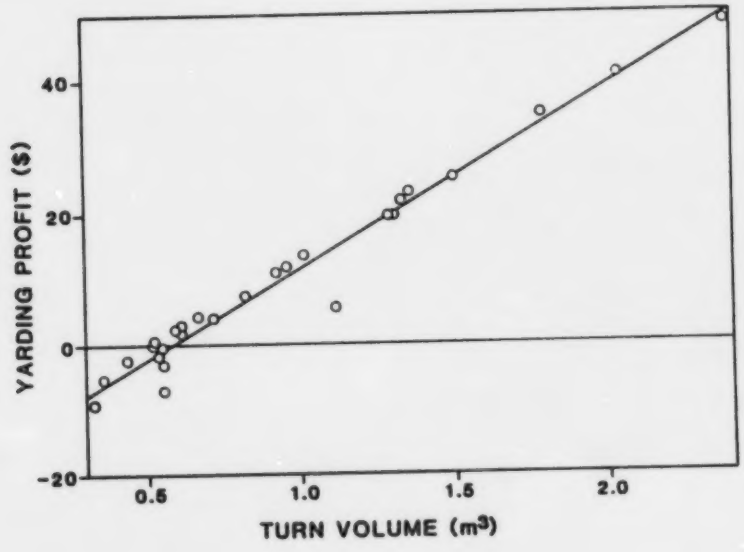



FIGURE J. Yarding Profit vs Turn Volume--
Douglas-Fir J-Grade Logs.

Regression analysis was done to predict the correlation between yarding profit and turn volume. Table 13 shows the total number of logs as well as the number of non-profitable logs for each of the lower-valued grades. It also shows the $r^2$ values and the coefficients for the regression lines.

The point where the regression line crosses the X-axis in Figure J is the marginal turn volume for Douglas-fir J-grade logs. The same point was calculated for each of the lower-value grades and is shown in Table 14. To help visualize the marginal log, the average diameter of an 8-m long marginal log is shown. For comparison, the smallest log observed for each grade is also shown.

The marginal turn volumes and log diameters shown in Table 14 assume there is only one log per turn. Logs below this limit are unprofitable to yard individually and must be handled differently to be profitable. The marginal log volume will decrease with multiple-log turns depending on the extra time required to hookup, yard, and unhook the second log. It will also decrease if loading and sorting charges are applied on a volume basis rather than piece basis. More research is required to determine if submarginal logs can be yarded profitably by bunching or other techniques.

TABLE 13. Yarding Profit vs Turn Volume.

| Species | Grade | No. of Logs | No. of Non-Profitable Logs | $r^2$ | Regression Coefficients Profit = f(volume) | |
|---|---|---|---|---|---|---|
| | | | | | Constant | Slope |
| Fir | J | 27 | 8 | 0.97 | -16.14 | 27.54 |
| | X | 3 | 3 | 0.99 | -13.44 | 9.14 |
| | Y | 1 | 1 | - | - | - |
| Cedar | J | 39 | 8 | 0.99 | -14.71 | 31.45 |
| | X | 5 | 3 | 0.98 | -15.42 | 12.18 |
| Hemlock | J | 69 | 28 | 0.97 | -15.62 | 25.44 |
| | X | 6 | 5 | 0.97 | -15.49 | 21.73 |
| Spruce | J | 17 | 4 | 0.98 | -14.24 | 23.92 |
| | X | 2 | 1 | - | - | - |
| | Y | 1 | 1 | - | - | - |
| Alder | - | 13 | 0 | 0.94 | -14.75 | 18.76 |

TABLE 14. Marginal Log Size.

| Species | Grade | Marginal Volume ($m^3$) | Avg Diameter of 8-m Long Marginal Log (cm) | Smallest Observed ($m^3$) | Submarginal (%) |
|---|---|---|---|---|---|
| Fir | J | 0.59 | 31 | 0.33 | 33 |
| | X | 1.47 | 48 | 0.16 | 85 |
| Cedar | J | 0.47 | 27 | 0.24 | 24 |
| | X | 1.27 | 45 | 0.18 | 82 |
| Hemlock | J | 0.61 | 31 | 0.15 | 46 |
| | X | 0.71 | 34 | 0.16 | 77 |
| Spruce | J | 0.60 | 32 | 0.40 | 33 |
| Alder | - | 0.78 | 35 | 0.37 | 7 |

It should be noted that approximately 1000 pieces were marked and 560 of these were scaled, but only 281 turns had their volumes and times recorded. The other pieces were lost because of shift schedules or illegible marks. The number of non-profitable logs in Table 13 refers only to the 281 turns but Table 14 shows the percentage of total scaled pieces which fell below the calculated marginal volume.

Tables 13 and 14 show that 24-46% of the J-grade logs were yarded at a loss when yarded individually. Further, 77-85% of the X-grade logs and 100% of the Y-grade logs were unprofitable. Profits cannot be maximized if these submarginal logs are yarded with the observed logging system.

Although field-test results show that yarding time, and thus cost, is primarily determined by yarding distance, Figure I shows that yarding profit for Douglas-fir J-grade logs appears to be independent of yarding distance. To examine this disparity, the sample logs were stratified by yarding distance and a marginal log volume was calculated for each yarding distance class. The logs were divided into four 50-m yarding distance classes. Hemlock J-grade logs were selected for this analysis because of their larger sample size. Table 15 shows the regression coefficients, the marginal turn volume, and the average diameter of an 8-m long marginal log. As expected, the marginal turn volume increases with yarding distance. However, the increase in volume is slight--the difference between the nearest yarding class and the farthest yarding class is only 0.14 $m^3$, and the diameter difference is 4 cm on an 8-m log.

TABLE 15. Hemlock J-Grade Logs--
Marginal Volume by Distance..

| Yarding Distance (m) | No. of Turns | Marginal Volume ($m^3$) | $r^2$ | Regression Coefficients | | Avg Diameter 8-m Long Log (cm) |
|---|---|---|---|---|---|---|
| | | | | Constant | Slope | |
| 0- 50 | 14 | 0.57 | 0.98 | -15.26 | 27.01 | 30 |
| 50-100 | 16 | 0.58 | 0.99 | -15.27 | 26.49 | 30 |
| 100-150 | 23 | 0.63 | 0.99 | -16.81 | 26.54 | 32 |
| 150-200 | 12 | 0.71 | 0.96 | -18.64 | 26.21 | 34 |

If yarding standards are to be determined by the marginal log, they must be defined in such terms that typical operating personnel will use them on a consistent basis. Some grades and species are always profitable and some are always submarginal, and these grades present the fewest problems in defining yarding standards. While it is technically feasible to define the marginal log by species, grade, size, and distance, the effect of distance on the yarding decision is present over a small volume range (approximately 0.14 $m^3$ for hemlock J-grade logs) and would be impractical to include in the standard. Therefore, the marginal log is defined by size for each species and grade as shown in Table 14.

7. Grapple Comparison and Line Speeds

Detailed-timing data were collected mainly to complete the marginal log analysis, however, they also provided information about some mechanical aspects of the yarder. It was found that a large grapple was better able to hold small logs than a smaller grapple. The time required to rehook logs after they slipped from the grapple dropped from 4.5% of yarding time to 2.3% with the large grapple. It was also found that line speeds, as well as outhaul and inhaul times, are affected by yarding distance. Appendix IX provides more detail on the grapple and line-speed calculations.

## CONCLUSIONS

The Madill 122 averaged 34.7 $m^3$ per PMH, or 232 $m^3$ per 8-hour shift, over the study. The average yarding cost was \$5.68/$m^3$. The yarder averaged 83.4% productive time and 88.5% availability over the study period. The average turn time varied from 1.07 to 1.39 min, including yarder and backspar moves, and short delays. The machine operated under good conditions and the setting layout obtained maximum benefit from the topography.

It was found that turn volume had only a small effect on inhaul times or turn cost. The major factor influencing turn cost was yarding distance. Turn cost increased from $3.08 per turn at 20 m, to $6.13 per turn at 180 m. However, turn volume had a major influence on cost per cubic metre, especially when yarding small timber. The cost per cubic metre at a 100-m yarding distance increased from $9.20/m³ with a 0.50-m³ turn, to $18.41/m³ with a 0.25-m³ turn. The same effect was seen in yarding profit analysis: the turn volume determines the yarding profit. Turn time and yarding distance had only minor influences on yarding profit.

The marginal turn volume and the diameter of an 8-m long marginal log for several log grades were calculated. Depending on the species, it was found that 24-46% of the J-grade logs were yarded at a loss. Similarly, 77-85% of the X-grade logs and 100% of the Y-grade logs could not cover their variable yarding costs. It was found that the marginal turn volume increased with yarding distance, but that the volume increase was slight. From an operational viewpoint, it would be difficult to implement a marginal log yarding standard which varied with yarding distance.

The calculated marginal turn volumes and log sizes assume one-log turns and other handling methods. The analysis did not show how much time could be spent in bunching several submarginal logs to make one profitable turn, nor did it show how tree-length yarding might affect profitability. If small logs were pre-sorted and handled in bundles at the log sort, their profitability would change. Small logs represent a significant portion of the total stand, and techniques must be developed to make them profitable. Further research is required to investigate some of these techniques.

Marginal log analysis does not show the profit in developing and logging the whole setting; it shows only the profit on individual logs. However, setting profit will be maximized if the yarding standard is based on marginal analysis. The amount of profit depends on the development, falling, overhead, and other sunk costs, as well as the proportion between profitable and non-profitable logs and the actual profit or loss on each log. This study does not attempt to define the profit for logging the whole setting.

Maximum productivity was obtained when the maximum yarding distance was 140-160 m. At shorter distances, the number of yarder and backspar moves caused productivity to drop. Move time was as high as 27% of productive time. At longer distances, it became necessary to use the guylines more often, which increased move times. Inhaul and outhaul time increased as expected as yarding distance increased, but it was also found that the average inhaul speed reached maximum at about a 120-m yarding distance and then decreased. Inhaul times from longer yarding distances were increased by both the longer distance and the lower average speed. Longer yarding distance on flat topography also made it more difficult to raise the grapple clear of the ground which increased hookup time.

The choice of grapple was found to influence yarder productivity. A small grapple dropped 7.4% of its turns, while a large grapple with more teeth dropped 5.1% of its turns. The time required to rehook the logs was reduced from 4.5% to 2.3% of yarding time.

The yarder had two main mechanical problems. Its original air compressors provided an inadequate air supply, so a third compressor was installed as a factory modification, and there were recurring problems with the winch interlock and mainline brake.

## APPENDIX I

## Machine Costs

| | Hitachi Backspar | Madill 122 Yarding Crane |
|---|---|---|
| **OWNERSHIP COSTS** | | |
| Purchase Price - Standard | $100 000 | $548 000 |
| Purchase Price - Extra Cost* | | $60 000 |
| Expected Life (yr) | 5 | 5 |
| Hours per Year (h) | 3000 | 3000 |
| Interest Rate (I) % | 10 | 10 |
| Insurance Rate (Ins) % | 1 | 1 |
| Purchase Price - As Equipped (P) | $100 000 | $608 000 |
| Salvage Value (S)=(0.2 * P) | $20 000 | $109 600 |
| Average Investment (AVI)=(P + S)/2 | $60 000 | $358 800 |
| Expected Life (H) | 15 000 | 15 000 |
| Loss in Resale Value ($/h)=(P-S)/H | $5.33 | $29.23 |
| Interest ($/h)(I*AVI)/h | $2.00 | $11.96 |
| Insurance ($/h)(Ins*AVI)/h | $0.20 | $1.20 |
| Total Ownership Costs | $7.53 | $42.38 |
| **OPERATING AND REPAIR COSTS** | | |
| Fuel Consumption (L/h) | 10 | 30 |
| Fuel Cost ($/L) | $0.35 | $0.35 |
| Operating Supply Cost per Year (O) | $3 000 | $50 000 |
| Annual Repair & Maintenance Cost (R) | $20 000 | $100 000 |
| Wages ($/h) | | $34.93 |
| Wage Benefit Loading (WBL) % | | 35 |
| Fuel Cost = (L/h)*($/L) | $3.50 | $10.50 |
| Lube & Oil Cost (0.1 * Fuel Cost) | $0.35 | $1.05 |
| Operating Supply Cost = (O/h) | $1.00 | $16.67 |
| Repair & Maintenance Cost = (R/h) | $6.67 | $33.33 |
| Gross Labour Cost | $0.00 | $53.34 |
| Total Operating and Repair Costs ($/h) | $11.52 | $114.89 |
| **OWNERSHIP AND OPERATING COSTS** | $19.05 | $157.27 |

**SYSTEM COST excludes interest** $164.36
**SYSTEM VARIABLE COST excludes ownership** $126.41

**NOTES:**

**Wage Calculation**

| | |
|---|---|
| Operator (includes WBL) | $23.94 |
| Hooktender (includes WBL) | $23.22 |
| Operators' Bonus | |
| (0.7 h per 8 h | $ 6.18 |
| @ overtime rate) | $53.34 |

*Extra-Cost Equipment

| | |
|---|---|
| Lights | $12 000 |
| Counterweight | 9 000 |
| Guarding | 2 000 |
| Rigging | 15 000 |
| Lines | 22 000 |
| | $60 000 |

APPENDIX II

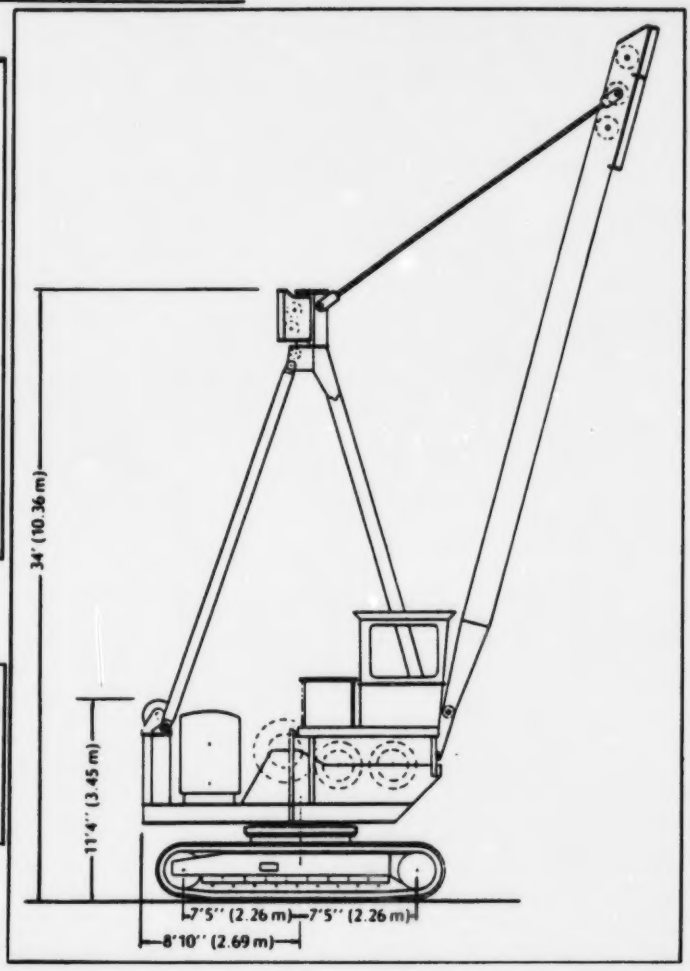
## Madill 122 Specifications

**Carrier Specifications**

**Model: B7H**
**Speed: 2.6 mph. [4.2 km/h]**
**Gradeability: 36%**
**Turning Radius: 13 ft. [3.96 m]**
**Track: B7H 30" [0.762 m] wide triple grouser**
**Sprocket: 25 teeth, 34" [863.6 mm] P.D.**
**Frame: Reinforced Box type**
**Swing Speed: 0 to 3.5 RPM**
**Ground Pressure: 11.5 psi [0.81 kg/sq. cm]**
**Controls: All controls are located in operator cab**
**Brakes: Multiple Disc Brakes**
**Final Drive: L&S, ratio 120/1**
**Motors: Rexroth A2V 180**
**Overall Length: 18 ft. [5.49 m]**
**Overall Width: 12 ft. [3.66 m]**
**Weight: 43,000 lbs. [19,505 kg]**

**122 Interlock Swing Yarder General Specifications**

**Type: 122**
**Model: 4-425**
**Engine Power: G.M.8V92TA [425 h.p.]**




TYPE 122 WINCH DRUM PERFORMANCE & CAPACITIES IN NON-INTERLOCK MODE
Pulls at stall or clutch slip-speeds at no load. Other line speed & pull combinations available by changing roller chain sprocket.

MARK:20 ENGINE: G.M.8V92TA TORQUE CONVERTER: Twin Disc Type 4 TRANSMISSION: Twin Disc TD-2800, Ratio 2-1

| DRUM | DIMENSIONS | | OPERATING CAPACITY | | MAXIMUM LINE PULL HIGH GEAR | | MAXIMUM LINE PULL LOW GEAR | | MAXIMUM LINE SPEED HIGH GEAR | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAIN | FLANGE 32" 81.3 cm<br>CORE 20" 50.8 cm<br>CORE LENGTH 28" 71.1 cm | | 2000' - 3/4" 609 m - 19.0 mm<br>1400' - 7/8" 427 m - 22.2 mm | | Bare 40381 lbs (18355 kg)<br>Mid 27179 lbs (12354 kg)<br>Full 22083 lbs. (10038 kg) | | 65121 lbs (29600 kg)<br>52598 lbs (23908 kg)<br>42735 lbs (19425 kg) | | Bare 1727 ft/min (526 m/min.)<br>Mid 2210 ft/min (673 m/min.)<br>Full 2764 ft/min (843 m/min.) | |
| SLACKPULLER | FLANGE 32" 81.3 cm<br>CORE 20" 50.8 cm<br>CORE LENGTH 28" 71.1 cm | | 2000' - 3/4" 609 m - 19.0 mm<br>1400' - 7/8" 427 m - 22.2 mm | | Bare 16496 lbs (7498 kg)<br>Mid 14138 lbs (6426 kg)<br>Full 11782 lbs (5355 kg) | | 32992 lbs (14996 kg)<br>26277 lbs (12053 kg)<br>23565 lbs. (10711 kg) | | Bare 1727 ft/min (526 m/min.)<br>Mid 2210 ft/min (673 m/min.)<br>Full 2764 ft/min (843 m/min.) | |
| HAULBACK | FLANGE 41-1/2" 105.4 cm<br>CORE 22" 55.9 cm<br>CORE LENGTH 28" 71.1 cm | | 5100' - 3/4" 1554 m - 19.0 mm<br>2900' - 7/8" 884 m - 22.2 mm | | Bare 14355 lbs (6525 kg)<br>Mid 12304 lbs (5593 kg)<br>Full 10254 lbs (4661 kg) | | 28711 lbs (13060 kg)<br>24609 lbs (11186 kg)<br>20507 lbs (9321 kg) | | Bare 1920 ft/min (579 m/min.)<br>Mid 2687 ft/min (819 m/min.)<br>Full 3585 ft/min (1093 m/min.) | |
| STRAW PULL-CLUTCH LIMITED | FLANGE 34" 86.4 cm<br>CORE 9-1/2" 24.1 cm<br>CORE LENGTH 9" 22.9 cm | | 10000' - 1/4" 3048 m - 6.3 mm<br>6400' - 5/16" 1951 m - 7.9 mm<br>4400' - 3/8" 1341 m - 9.5 mm | | Bare 16000 lbs (7273 kg)<br>Mid 7619 lbs. (3463 kg)<br>Full 4700 lbs. (2136 kg) | | | | Bare 1918 ft/min. (584 m/min.)<br>Mid 6475 ft/min. (1264 m/min.)<br>Full 7245 ft/min. (2289 m/min.) | |
| TOPPING | FLANGE 19" 48.3 cm<br>CORE 8-5/8" 21.9 cm<br>CORE LENGTH 11" 27.9 cm | | 340' - 3/4" 104 m - 19.0 mm | | Bare<br>Mid<br>Full | | 8522 lbs (3874 kg)<br>6520 lbs. (2964 kg)<br>4557 lbs. (2071 kg) | | Bare 73 ft/min (22 m/min.)<br>Mid 112 ft/min. (34 m/min.)<br>Full 166 ft/min. (51 m/min.) | |
| GUYLINE | FLANGE 19" 48.3 cm<br>CORE 8-5/8" 21.9 cm<br>CORE LENGTH 11" 27.9 cm | | 795' - 1" 60 m - 25.4 mm<br>256' - 7/8" 78 m - 22.2 mm | | Bare<br>Mid<br>Full | | 8522 lbs. (3874 kg)<br>6520 lbs. (2964 kg)<br>4557 lbs. (2071 kg) | | Bare 73 ft/min (22 m/min.)<br>Mid 112 ft/min (34 m/min.)<br>Full 166 ft/min (51 m/min.) | |

## APPENDIX III

## Shift-Level Time Distribution

| | Hours | | | Code[1] |
|---|---|---|---|---|
| | On Shift | Off Shift | Total | |
| PRODUCTIVE | | | | |
| Gross Yarding | 479.91 | 0 | 479.91 | 11 |
| Move/Rig | 18.71 | 0 | 18.71 | 121 |
| Change Grapple | 1.65 | 0 | 1.65 | 124 |
| NON-PRODUCTIVE | | | | |
| Operational | | | | |
| Reconnaissance/Plan Work | 0.19 | 0 | 0.19 | 2151 |
| Repair Backspar | 13.76 | 0 | 13.76 | 21631 |
| Move Backspar | 1.53 | 0 | 1.53 | 21632 |
| Backspar Stuck | 1.94 | 0 | 1.94 | 21633 |
| Unexplained Delay | 4.08 | 0 | 4.08 | 217 |
| Organizational | | | | |
| Delay--Trailbuilder | 1.19 | 0 | 1.19 | 22122 |
| Delay--Loader | 1.05 | 0 | 1.05 | 22125 |
| Operator Working Elsewhere | 0.34 | 0 | 0.34 | 2231 |
| Safety Meeting | 0.36 | 0 | 0.36 | 22331 |
| Shift Change | 6.18 | 0 | 6.18 | 2235 |
| Mechanical Wait | | | | |
| Wait Parts | 7.95 | 0 | 7.95 | 231 |
| Wait Mechanic | 1.99 | 0 | 1.99 | 232 |
| REPAIR DELAY | | | | |
| Carrier Repair | | | | |
| Carrier Lights | 1.07 | 0 | 1.07 | 24126 |
| Minor Welding | 0.44 | 0 | 0.44 | 24131 |
| Radio | 0.29 | 0 | 0.29 | 24144 |
| Carrier Air Lines | 0.53 | 0 | 0.53 | 24181 |
| Carrier Air Compressor | 3.21 | 16.00 | 19.21 | 24182 |
| Power System Repair | | | | |
| Clutch--Carrier Drive | 0.46 | 0 | 0.46 | 24222 |
| Winch Controls | 2.76 | 0 | 2.76 | 24231 |
| Winch Clutch/Friction | 1.10 | 4.00 | 5.10 | 24232 |
| Water Pump | 0.41 | 0 | 0.41 | 24246 |
| Winch/Lines/Grapple | | | | |
| Winch Hydraulic Controls | 0.92 | 0 | 0.92 | 24315 |
| Minor Welding | 0.67 | 0 | 0.67 | 24331 |
| Major Welding | 4.26 | 0 | 4.26 | 24332 |
| Cable | 10.65 | 0 | 10.65 | 23241 |
| Grapple | 4.52 | 0 | 4.52 | 24343 |
| Brakes | 3.04 | 0 | 3.04 | 24353 |
| Winch Air Line | 1.01 | 0 | 1.01 | 24361 |
| Air Actuator | 0.98 | 0 | 0.98 | 24363 |
| Wearing Parts--Cable | 9.81 | 0 | 9.81 | 24371 |
| Unspecified Repairs | 0.15 | 0 | 0.15 | 245 |
| Service Delay | | | | |
| Carrier Service | 1.61 | 0 | 1.61 | 251 |
| Winch/Line/Grapple Service | 1.93 | 0 | 1.93 | 253 |
| General Service | 0.17 | 0 | 0.17 | 255 |
| Warm Up | 1.24 | 0 | 1.24 | 2551 |
| Daily Service | 6.43 | 0 | 6.43 | 2552 |
| Fuelling | 1.43 | 0 | 1.43 | 2553 |
| Weekend | 0.00 | 198.00 | 198.00 | 321 |
| Statutory Holiday | 0.00 | 24.00 | 24.00 | 322 |
| No Work Scheduled | 0.00 | 8.00 | 8.00 | 323 |

[1] FERIC code for time distribution.

APPENDIX IV

Cycle Element Definitions

| Time Element | Begins | Ends |
|---|---|---|
| Outhaul | When grapple starts travel away from yarder. | When grapple stops at a target log. |
| Hookup | End of outhaul. | When grapple begins to travel with one or more pieces. |
| Inhaul | End of hookup. | When incoming turn stops above log deck. |
| Unhook | End of Inhaul. | When grapple has dropped the log and is free to commence next function. |
| Deck | When yarder grasps a log already in the log deck to straighten or re-pile the deck. | When grapple starts travel away from log deck. |
| Rehook | End of hookup. | When grapple has secured a log and returns to position where original log was lost. |
| Cherry-Pick | When grapple starts travel away from the yarder. | When grapple has deposited log in the log deck. |
| Move Yarder | When grapple stops and crew prepares to move yarder.[1] | When machinery is in position to commence productive function. |
| Move Backspar | When grapple stops and crew prepares to move backspar.[2] | When machinery is in position to commence productive function. |
| Delay | When a productive function is interrupted. | When productive function recommences. |

[1] Includes time when both yarder and backspar are moved.
[2] Includes time for hooker to walk to backspar and time when backspar pushes logs closer to yarder.

## APPENDIX V

### Field Tables for Estimated Piece Size
### 0.5 $m^3$ Classes

8-m Long

| Top | Butt[1] 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|
| 10 | 0 | 1 | 2 | 4 | 6 | 9 |
| 20 | 1 | 1 | 3 | 4 | 7 | 9 |
| 30 | 1 | 2 | 3 | 5 | 7 | 10 |
| 40 | 1 | 2 | 3 | 5 | 7 | 10 |
| 50 | 2 | 3 | 4 | 6 | 8 | 11 |

10-m Long

| Top | Butt 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|
| 10 | 0 | 1 | 3 | 5 | 8 | 11 |
| 20 | 1 | 2 | 3 | 5 | 8 | 12 |
| 30 | 1 | 2 | 4 | 6 | 9 | 12 |
| 40 | 2 | 3 | 4 | 6 | 9 | 13 |
| 50 | 2 | 3 | 5 | 7 | 10 | 13 |

12-m Long

| Top | Butt 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|
| 10 | 0 | 2 | 3 | 6 | 10 | 14 |
| 20 | 1 | 2 | 4 | 6 | 10 | 14 |
| 30 | 1 | 2 | 4 | 7 | 10 | 14 |
| 40 | 2 | 3 | 5 | 8 | 11 | 15 |
| 50 | 3 | 4 | 6 | 8 | 12 | 16 |

15-m Long

| Top | Butt 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|
| 10 | 1 | 2 | 4 | 8 | 12 | 17 |
| 20 | 1 | 2 | 5 | 8 | 12 | 17 |
| 30 | 2 | 3 | 5 | 9 | 13 | 18 |
| 40 | 2 | 4 | 6 | 9 | 14 | 19 |
| 50 | 3 | 5 | 7 | 10 | 15 | 20 |

| Class Volumes | | | | | | | |
|---|---|---|---|---|---|---|---|
| Class | 0 | 1 | 2 | 3 | 4 | 5 | 20 |
| Volume ($m^3$) | 0.125 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 ..... | 10.0 |

[1] Top and butt diameters in centimeters.

APPENDIX VI

## Predicted Yarding Cost ($/m³)

| Turn Volume (m³) | 0.25 | 0.50 | 1.00 | 2.00 | 3.00 | 4.00 |
|---|---|---|---|---|---|---|
| Yarding Distance (m) | | | | | | |
| 20 | 12.30 | 6.15 | 3.08 | 1.54 | 1.03 | 0.77 |
| 40 | 13.83 | 6.91 | 3.46 | 1.73 | 1.15 | 0.86 |
| 60 | 15.35 | 7.68 | 3.84 | 1.92 | 1.28 | 0.96 |
| 80 | 16.88 | 8.44 | 4.22 | 2.11 | 1.41 | 1.06 |
| 100 | 18.41 | 9.20 | 4.60 | 2.30 | 1.53 | 1.15 |
| 120 | 19.93 | 9.97 | 4.98 | 2.49 | 1.66 | 1.25 |
| 140 | 21.46 | 10.73 | 5.37 | 2.68 | 1.79 | 1.34 |
| 160 | 22.99 | 11.49 | 5.75 | 2.87 | 1.92 | 1.44 |
| 180 | 24.51 | 12.26 | 6.13 | 3.06 | 2.04 | 1.53 |
| 200 | 26.04 | 13.02 | 6.51 | 3.26 | 2.17 | 1.63 |
| 220 | 27.57 | 13.78 | 6.89 | 3.45 | 2.30 | 1.72 |

| Yarding Distance (m) | 50 | 100 | 150 | 200 |
|---|---|---|---|---|
| Turn Volume (m³) | | | | |
| 0.25 | 14.59 | 18.41 | 22.22 | 26.04 |
| 0.50 | 7.30 | 9.20 | 11.11 | 13.02 |
| 0.75 | 4.86 | 6.14 | 7.41 | 8.68 |
| 1.00 | 3.65 | 4.60 | 5.56 | 6.51 |
| 1.25 | 2.92 | 3.68 | 4.44 | 5.21 |
| 1.50 | 2.43 | 3.07 | 3.70 | 4.34 |
| 2.00 | 1.82 | 2.30 | 2.78 | 3.26 |
| 2.50 | 1.46 | 1.84 | 2.22 | 2.60 |
| 3.00 | 1.22 | 1.53 | 1.85 | 2.17 |
| 3.50 | 1.04 | 1.31 | 1.59 | 1.86 |
| 4.00 | 0.91 | 1.15 | 1.39 | 1.63 |

**Note:**

Estimated cost of yarding crane and backspar is $164.36/h.

APPENDIX VII

Log Values--Vancouver Log Market ($/m³)

| Grade | Douglas-fir | Western Red Cedar | Western Hemlock | Spruce | Alder |
|---|---|---|---|---|---|
| B | 127 | | | | |
| C | 76 | | | | |
| H | 63 | 75 | | 74 | |
| I | 55 | 62 | 47 | 54 | |
| J | 39 | 45 | 38 | 37 | |
| M | | 50 | | | |
| X | 23 | 23 | 33 | 33 | |
| Y | 8 | | | 2 | |
| - | | | | | 30 |

Note:

1) Three-month average to February 13, 1987.
2) Rounded to nearest dollar.
3) Stumpage set at 8% of market value.
4) Estimated charges to be deducted from market value:
   a) Loading $ 4.10/piece
   b) Hauling $ 6.70/m³
   c) Sort/Boom $ 8.25/piece
   d) Towing $ 1.00/m³
   e) Sales 2.5% of market value

## APPENDIX VIII

## Yarding Profits--Douglas-Fir J-Grade Logs

| Scaling Number[1] | Merch. Volume | No. of Logs | Yarding Distance (m) | Inhaul Time (min) | Net Yarding Time (min) | Turn Time (min) | Yarding Cost ($) | Log Value ($) | Yarding Profit ($) |
|---|---|---|---|---|---|---|---|---|---|
| 310.2 | 0.33 | 1 | 145 | 0.60 | 2.09 | 2.81 | 5.92 | -3.34 | -9.26 |
| 20.2 | 0.36 | 2 | 30 | 0.11 | 0.94 | 1.43 | 3.02 | -2.55 | -5.56 |
| 609.2 | 0.44 | 1 | 40 | | 0.43 | 1.04 | 2.21 | -0.38 | -2.59 |
| 242.2 | 0.52 | 1 | 70 | 0.17 | 0.54 | 0.95 | 2.01 | 1.82 | -0.19 |
| 23.2 | 0.53 | 1 | 25 | 0.09 | 0.39 | 0.77 | 1.63 | 2.00 | 0.37 |
| 273.1 | 0.54 | 1 | 120 | 0.28 | 1.49 | 2.11 | 4.45 | 2.44 | -2.02 |
| 419.2 | 0.55 | 1 | 100 | 0.27 | 0.87 | 1.57 | 3.32 | 2.72 | -0.60 |
| 78.1 | 0.56 | 1 | 130 | 0.66 | 3.75 | 4.82 | 10.16 | 2.76 | -7.40 |
| 449.2 | 0.56 | 1 | 90 | 0.18 | 2.00 | 2.93 | 6.17 | 2.78 | -3.39 |
| 48.2 | 0.60 | 1 | 45 | 0.13 | 0.46 | 0.85 | 1.80 | 3.87 | 2.07 |
| 459.2 | 0.61 | 1 | 90 | 0.17 | 0.74 | 1.41 | 2.99 | 4.36 | 1.37 |
| 12.2 | 0.62 | 1 | 20 | | 0.34 | 0.71 | 1.50 | 4.39 | 2.89 |
| 5.1 | 0.67 | 1 | 45 | 0.13 | 0.40 | 0.80 | 1.70 | 5.87 | 4.17 |
| 300.2 | 0.72 | 1 | 140 | 0.31 | 1.06 | 1.57 | 3.32 | 7.18 | 3.86 |
| 436.2 | 0.82 | 1 | 35 | 0.18 | 0.61 | 1.26 | 2.66 | 9.98 | 7.32 |
| 200.2 | 0.92 | 1 | 30 | | 0.44 | 0.83 | 1.75 | 12.68 | 10.93 |
| 2.2 | 0.96 | 1 | 20 | | 0.52 | 0.92 | 1.96 | 13.77 | 11.82 |
| 17.2 | 1.01 | 1 | 30 | 0.08 | 0.38 | 0.76 | 1.60 | 15.20 | 13.60 |
| 85.1 | 1.12 | 1 | 140 | 0.98 | 4.82 | 6.10 | 12.87 | 18.03 | 5.17 |
| 431.2 | 1.29 | 1 | 105 | 0.21 | 0.95 | 1.67 | 3.52 | 22.80 | 19.28 |
| 134.1 | 1.31 | 1 | 140 | 0.34 | 1.27 | 1.85 | 3.90 | 23.31 | 19.41 |
| 256.1 | 1.34 | 1 | 60 | 0.20 | 0.64 | 1.09 | 2.31 | 23.99 | 21.68 |
| 201.1 | 1.36 | 1 | 40 | | 0.36 | 0.76 | 1.60 | 24.61 | 23.02 |
| 83.1 | 1.51 | 1 | 140 | 0.39 | 1.09 | 1.63 | 3.44 | 28.61 | 25.17 |
| 2.1 | 1.79 | 1 | 25 | | 0.33 | 0.72 | 1.52 | 36.35 | 34.83 |
| 1.1 | 2.04 | 1 | 60 | 0.13 | 0.71 | 1.18 | 2.48 | 43.09 | 40.61 |
| 87.1 | 2.39 | 1 | 145 | 0.40 | 1.36 | 1.95 | 4.13 | 52.60 | 48.48 |

[1] FERIC scale number consisting of log number and scaling group.

APPENDIX IX

## Grapple Comparison and Line Speeds

The contractor used two different grapples during the study period. Both were built by the contractor. One grapple had a maximum opening of 150 cm, and the other grapple had a maximum 190-cm opening. In addition, the larger grapple had extra teeth deep in its throat which provided a more secure grip on small logs. These extra teeth can be seen in Figure IX-A. FERIC noticed that many logs slipped out of the small grapple during inhaul.

FIGURE IX-A. Yarding Grapple--190-cm Opening.

Rehook was defined as the time required to rehook a log after it had slipped out of the grapple. Rehook normally occurred within a few metres of the original log location. The number of occurrences of rehooking and their duration were recorded. The grapples were changed during Week 1 and Table IX-1 shows its effect. The occurrence of rehook dropped from 7.4% of turns to 5.1%, an improvement of 31%, and the time dropped from 4.5% of total yarding time to 2.3%, an improvement of 49%. This shows the importance of matching the grapple to the logging conditions. In this location, the larger grapple was better able to handle smaller logs.

TABLE IX-1. Comparison of Rehook Times.

| | Week 1 | | | Weeks 1-3 |
|---|---|---|---|---|
| | Small Grapple | Large Grapple | Combined | Large Grapple |
| No. of Turns | 771 | 448 | 1219 | 1287 |
| No. of Turns with Rehook | 57 | 25 | 82 | 83 |
| Percent | 7.4 | 5.1 | 6.7 | 6.4 |
| Yarding Time (min) | 865 | 478 | 1343 | 1105 |
| Rehook Time (min) | 39 | 11 | 49 | 43 |
| Percent | 4.5 | 2.3 | 3.6 | 3.9 |

The average outhaul and inhaul line speed at each of the observed yarding distances was calculated. Figure IX-B shows the inhaul and outhaul speeds for all weeks combined.

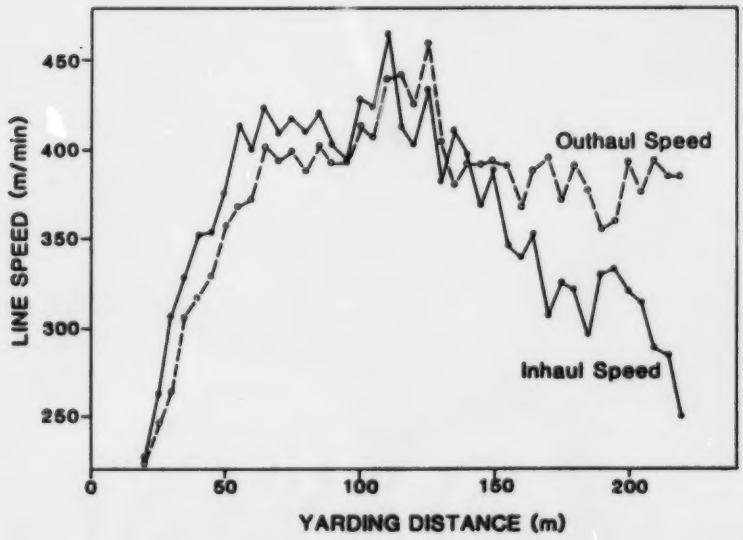



FIGURE IX-B. Outhaul and Inhaul Speeds vs Yarding Distance.

Turns which originate close to the roadside show the lowest inhaul speed because the log must be swung into lead before the operator accelerates to full throttle. This action consumes time with little gain in distance and leads to lower average inhaul speeds. Also, the turn cannot be accelerated to full throttle in such a short distance.

Inhaul speeds quickly reach a level of approximately 410 m/min at 70-m yarding distance and climb to approximately 440 m/min at 120-m yarding distance. The average speed starts to decrease at distances beyond 120 m. This results from the decreased effective size of the mainline drum and decreased ground clearance.

Outhaul speeds show the same trend at short distances as inhaul speeds. Maximum average outhaul speed of 460 m/min is reached at a 125-m yarding distance. The outhaul speed decreases after this point, but not to the same extent as inhaul speed. This is due to the increasing effective size of the haulback drum as distance increases. The average outhaul speed at distances of 180-200 m is about 380 m/min. The rated line speed of the Madill 122 at mid-drum is 673 m/min for the mainline and slackpuller, and 819 m/min for the haulback. Clearly, the rated speed can be used only for comparison between machines, and not to calculate actual inhaul and outhaul times.